Earth Structure from Free Oscillations and Travel Times†

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An extensive set of reliable gross Earth data has been inverted to obtain a new estimate of the radial variations of seismic velocities and density in the Earth. The basic data set includes the observed mass and moment of inertia, the averaged periods of free oscillation, and five new sets of differential travel-time data. The eigenperiod data was drawn mainly from the Dziewonski–Gilbert study. The differential travel-time data consists of the times of $PcP-P$, $ScS-S$, $P_{AB}'-P_{DF}'$ and $P_{BC}'-P_{DF}'$. These data were inverted using the linear estimation algorithm described by Jordan (PhD Thesis, California Institute of Technology, 1972). A simple but realistic starting model was constructed based on a number of physical assumptions, such as requiring the Adams–Williamson relation to hold in the lower mantle and core. By using baseline-insensitive differential travel times and averaged eigenperiods, a considerable improvement in both the quality of the fit and the resolving power has been realized. The spheroidal and torodial data are fit on the average to 0·04 and 0·08 per cent, respectively. The final model, designated model B1, also agrees with Rayleigh and Love wave phase and group velocity data.

For model B1, the travel times of P waves are about 0·8 s later than the 1968 Seismological Tables with residuals decreasing with distance, in agreement with Cleary & Hales and other recent studies. PcP times are within 0·2 s of the 1968 Tables. PKP and $PKiKP$ times, in general, are within 0·5 s of recent studies. For PKP, the endpoint A occurs at 176°, the B caustic point is at 145°, the point C is at 157°, and the point D is at 110°. The precursors to P_{DF}' at distances less than 145° have been interpreted as scattering off lateral heterogeneities; there are no GH or IJ branches in this model. The travel times of S are 5–10 s later than the J.B. Tables in the distance range 30° to 95°, with residuals increasing with distance.

Model B1 is characterized by an upper mantle with a high, 4·8 $km\,s^{-1}$, Sn velocity and normal, 3·32 $g\,cm^{-3}$, density. A low-velocity zone for S is required by the data, but a possible low-velocity channel for compressional waves is not resolvable by the basic data set. The upper mantle transition zone contains two discontinuities at depths of 420 and 671 km. Between these discontinuities the shear velocity decreases with depth. The radius of the core, fixed by $PcP-P$ times, is 3485 km, and the radius of the inner core–outer core boundary is 1215 km. There are no other first-order discontinuities in the core model. The shear velocity in the inner core is about 3·5 $km\,s^{-1}$, confirming the value obtained by Dziewonski & Gilbert.

Resolving kernels, which indicate to what level of detail the final model can be discussed, have been computed. A density inversion below the lithosphere, for example, cannot be resolved by the data we use, and one can only discuss the average density in the upper several hundred kilometres of the mantle. On the other hand, the upper mantle shear wave low-velocity zone is resolvable.

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I	Radius (km)	Depth (km)	VP (km s^{-1})	VS (km s^{-1})	ρ (g cm^{-3})	ϕ (km^2 s^{-2})	K (kb)	μ (kb)	λ (kb)	σ	Pressure (kb)	Grav (cm s^{-2})
1	1	6370	11.20	3.50	12.58	139.11	13721	1540	12694	0.4459	3609	0
2	100	6271	11.20	3.50	12.57	139.11	13716	1541	12689	0.4459	3606	52
3	200	6171	11.20	3.50	12.56	139.12	13700	1539	12674	0.4458	3598	78
4	300	6071	11.20	3.50	12.53	139.14	13671	1535	12648	0.4459	3586	110
5	400	5971	11.20	3.50	12.52	139.16	13665	1532	12643	0.4459	3570	144
6	500	5871	11.20	3.50	12.51	139.18	13663	1531	12642	0.4460	3550	178
7	600	5771	11.20	3.50	12.51	139.20	13658	1528	12639	0.4461	3525	212
8	700	5671	11.20	3.49	12.50	139.19	13649	1523	12633	0.4462	3496	247
9	800	5571	11.19	3.48	12.50	139.12	13644	1517	12632	0.4464	3463	281
10	900	5471	11.19	3.48	12.49	139.09	13630	1510	12623	0.4466	3426	316
11	1000	5371	11.19	3.47	12.46	139.22	13609	1499	12610	0.4469	3384	350
12	1100	5271	11.21	3.46	12.39	139.57	13571	1485	12581	0.4472	3339	385
13	1215	5156	11.22	3.46	12.28	139.87	13492	1467	12513	0.4475	3281	423
14	1215	5156	10.14	0.0	12.11	102.91	12460	0	12460	0.5000	3281	423
15	1300	5071	10.15	0.0	12.08	102.99	12444	0	12444	0.5000	3236	450
16	1400	4971	10.15	0.0	12.04	103.06	12411	0	12411	0.5000	3180	482
17	1500	4871	10.14	0.0	11.99	102.85	12334	0	12334	0.5000	3120	514
18	1600	4771	10.12	0.0	11.93	102.39	12219	0	12219	0.5000	3056	546
19	1700	4671	10.07	0.0	11.87	101.47	12042	0	12042	0.5000	2990	578
20	1800	4571	10.00	0.0	11.80	100.08	11805	0	11805	0.5000	2919	609
21	1900	4471	9.93	0.0	11.72	98.65	11561	0	11561	0.5000	2846	640
22	2000	4371	9.86	0.0	11.64	97.14	11307	0	11307	0.5000	2769	671
23	2100	4271	9.78	0.0	11.56	95.59	11048	0	11048	0.5000	2690	701
24	2200	4171	9.70	0.0	11.47	94.00	10785	0	10785	0.5000	2607	731
25	2300	4071	9.62	0.0	11.39	92.57	10542	0	10542	0.5000	2522	760
26	2400	3971	9.55	0.0	11.30	91.23	10309	0	10309	0.5000	2434	790
27	2500	3871	9.46	0.0	11.21	89.51	10032	0	10032	0.5000	2343	818
28	2600	3771	9.35	0.0	11.11	87.49	9718	0	9718	0.5000	2250	846
29	2700	3671	9.24	0.0	11.00	85.35	9388	0	9388	0.5000	2155	874
30	2800	3571	9.11	0.0	10.88	82.92	9023	0	9023	0.5000	2058	901
31	2900	3471	8.96	0.0	10.76	80.21	8628	0	8628	0.5000	1959	928
32	3000	3371	8.79	0.0	10.62	77.30	8209	0	8209	0.5000	1858	954
33	3100	3271	8.63	0.0	10.48	74.41	7797	0	7797	0.5000	1756	979
34	3200	3171	8.46	0.0	10.33	71.62	7400	0	7400	0.5000	1653	1003
35	3300	3071	8.31	0.0	10.19	68.99	7026	0	7026	0.5000	1549	1026
36	3400	2971	8.16	0.0	10.04	66.52	6676	0	6676	0.5000	1444	1049
37	3485	2886	8.02	0.0	9.90	64.36	6373	0	6373	0.5000	1354	1068
38	3485	2886	13.67	7.27	5.58	116.38	6489	2948	4523	0.3027	1354	1068
39	3510	2861	13.67	7.27	5.56	116.35	6466	2934	4510	0.3029	1340	1064
40	3550	2821	13.66	7.26	5.54	116.32	6443	2916	4498	0.3033	1316	1059

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41	3625	2746	13.63	7.22	5.50	116.09	6385	2871	4471	0.3045	1272	1049
42	3700	2671	13.57	7.19	5.46	115.28	6294	2822	4412	0.3049	1229	1041
43	3775	2596	13.49	7.16	5.42	113.67	6160	2775	4309	0.3041	1187	1034
44	3850	2521	13.40	7.13	5.38	111.84	6014	2730	4194	0.3029	1145	1027
45	3925	2446	13.31	7.09	5.34	109.99	5870	2686	4079	0.3015	1104	1021
46	4000	2371	13.22	7.06	5.30	108.16	5727	2642	3966	0.3001	1063	1016
47	4075	2296	13.13	7.03	5.26	106.36	5597	2601	3863	0.2988	1023	1011
48	4150	2221	13.03	6.99	5.22	104.68	5469	2555	3765	0.2979	984	1008
49	4225	2146	12.95	6.96	5.19	103.12	5347	2509	3674	0.2971	944	1004
50	4300	2071	12.86	6.92	5.15	101.55	5227	2465	3583	0.2962	905	1001
51	4375	1996	12.77	6.88	5.11	99.84	5102	2422	3487	0.2951	867	999
52	4450	1921	12.68	6.85	5.07	98.13	4978	2380	3391	0.2938	829	997
53	4525	1846	12.59	6.81	5.04	96.63	4866	2336	3309	0.2931	791	996
54	4600	1771	12.50	6.77	5.00	95.13	4755	2293	3226	0.2923	754	994
55	4675	1696	12.41	6.74	4.96	93.49	4638	2253	3136	0.2909	716	994
56	4750	1621	12.33	6.71	4.92	92.10	4535	2214	3058	0.2901	680	993
57	4825	1546	12.25	6.67	4.89	90.62	4427	2174	2977	0.2890	643	993
58	4900	1471	12.16	6.64	4.85	88.99	4313	2136	2888	0.2874	607	993
59	4975	1396	12.06	6.59	4.81	87.59	4211	2089	2819	0.2872	571	993
60	5050	1321	11.97	6.55	4.77	86.07	4103	2044	2740	0.2864	535	993
61	5125	1246	11.86	6.50	4.72	84.34	3984	1998	2651	0.2851	500	994
62	5200	1171	11.75	6.47	4.68	82.36	3854	1956	2549	0.2829	465	994
63	5275	1096	11.64	6.44	4.64	80.15	3715	1920	2435	0.2796	430	995
64	5350	1021	11.52	6.39	4.59	78.30	3594	1871	2346	0.2781	395	996
65	5425	946	11.39	6.33	4.55	76.31	3469	1824	2253	0.2763	361	997
66	5500	871	11.26	6.28	4.50	74.19	3340	1778	2154	0.2739	327	998
67	5550	821	11.17	6.25	4.47	72.72	3252	1746	2087	0.2722	305	999
68	5600	771	11.07	6.21	4.44	71.18	3162	1712	2020	0.2706	283	1000
69	5650	721	10.97	6.17	4.41	69.71	3075	1677	1957	0.2693	261	1000
70	5700	671	10.88	6.12	4.38	68.39	2996	1642	1901	0.2683	239	1001
71	5700	671	10.08	5.21	4.05	65.37	2644	1098	1911	0.3175	239	1001
72	5725	646	10.01	5.21	4.02	64.03	2575	1092	1846	0.3141	228	1001
73	5750	621	9.95	5.22	4.00	62.62	2503	1088	1777	0.3100	218	1000
74	5775	596	9.88	5.23	3.97	61.16	2430	1086	1706	0.3055	208	1000
75	5800	571	9.81	5.24	3.95	59.66	2355	1084	1632	0.3004	199	1000
76	5825	546	9.75	5.26	3.92	58.13	2280	1084	1558	0.2948	189	999
77	5850	521	9.68	5.27	3.90	56.58	2205	1084	1482	0.2887	179	999
78	5875	496	9.61	5.29	3.87	55.05	2131	1084	1408	0.2825	169	999
79	5900	471	9.54	5.31	3.85	53.56	2060	1083	1338	0.2763	160	998
80	5925	446	9.48	5.32	3.82	52.14	1992	1079	1272	0.2705	150	998

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81	5951	420	8.41	5.32	3.80	50.76	1926	1074	1210	0.2649	140	997
82	5951	420	8.75	4.67	3.58	47.61	1706	780	1186	0.3017	140	997
83	5975	396	8.71	4.66	3.57	46.79	1668	775	1151	0.2988	132	997
84	6000	371	8.66	4.66	3.54	46.02	1630	768	1118	0.2965	123	996
85	6050	321	8.56	4.60	3.49	44.96	1569	739	1076	0.2964	105	994
86	6100	271	8.46	4.50	3.44	44.53	1530	695	1067	0.3028	88	992
87	6150	221	8.35	4.37	3.39	44.26	1498	648	1066	0.3110	71	990
88	6175	196	8.30	4.34	3.37	43.79	1473	633	1051	0.3119	63	989
89	6200	171	8.25	4.35	3.35	42.77	1432	633	1009	0.3072	54	988
90	6225	146	8.19	4.37	3.34	41.60	1388	637	962	0.3008	46	987
91	6250	121	8.13	4.44	3.33	39.88	1327	656	889	0.2878	38	986
92	6271	100	8.08	4.53	3.32	38.05	1264	681	810	0.2717	31	986
93	6271	100	8.08	4.53	3.32	38.05	1264	681	810	0.2717	31	986
94	6290	81	8.04	4.62	3.32	36.21	1202	708	730	0.2537	25	985
95	6310	61	8.00	4.72	3.32	34.24	1135	738	643	0.2327	18	984
96	6330	41	7.95	4.80	3.31	32.52	1076	762	568	0.2136	12	984
97	6350	21	7.91	4.83	3.30	31.45	1037	769	524	0.2026	5	983
98	6350	21	6.20	3.40	2.79	23.03	642	322	427	0.2850	5	983
99	6360	11	6.20	3.40	2.79	23.03	642	322	427	0.2850	3	982
100	6371	0	6.20	3.40	2.79	23.03	642	322	427	0.2850	0	981